TITANIUM-COPPER ALLOY HAVING EXCELLENT CONDUCTIVITY AND METHOD OF PRODUCING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a titanium-copper alloy having excellent conductivity.

2. Description of the Related Art

As electronic devices have become smaller and more light-weight, electric and electronic parts have also become smaller and more light-weight. When a connector becomes thinner and more small-pitched, a contact has a further reduced cross-sectional area. In order to compensate the decrease in contact pressure and conductivity caused by the reduced cross-sectional area, a metal material used as the contact should have high strength and conductivity.

In recent years, age-hardening copper alloys have been widely used as copper alloys having high strength. A supersaturated solid solution that is solution-treated is subjected to the aging treatment, whereby finely deposited matter is uniformly dispersed into the alloy to improve its strength.

Among the age-hardening copper alloys, a copper alloy containing Ti (hereinafter referred to as "titanium-copper alloy") as disclosed in JIS C1990 has high mechanical

strength and excellent bending properties, and thus is widely used as various terminals of electronic devices or connectors.

A high beryllium-copper alloy (JIS C1720) is also an age-hardening copper alloy having high strength. The titanium-copper alloy has the same strength but superior stress-relaxation resistance than high beryllium-copper alloy. Accordingly, the titanium-copper alloy is more suitable than high beryllium-copper alloy in the manufacture of burn-in sockets, which require heat resistance (see Japanese Unexamined Patent Application Publication Nos. 07-258803 and 2002-356726).

Japanese Unexamined Patent Application Publication No. 07-258803 discloses a titanium-copper alloy having excellent bending properties and stress-relaxation resistance. Such titanium-copper alloy has a maximum conductivity of about 15% IACS. Japanese Unexamined Patent Application Publication No. 2002-356726 discloses a titanium-copper alloy having both strength and bending properties, but its maximum conductivity is about 15% IACS. Thus, the conventional titanium-copper alloy has poor conductivity as low as 15% IACS, which is lower than that (20% IACS) of the high beryllium-copper alloy. This prevents the titanium-copper alloy from being used for applications that require high conductivity instead of the high beryllium-copper alloy.

A low-cost titanium-copper alloy having excellent stress-relaxation resistance can be used if it has substantially the same conductivity as that of the high beryllium-copper alloy.

SUMMARY OF THE INVENTION

An object of the present invention is to improve the conductivity of the titanium-copper alloy without decreasing its strength.

Through intensive studies by the present inventors, a titanium-copper alloy having a desired conductivity and strength can be provided by adjusting the amount of a Cu-Ti intermetallic compound phase within an optimum range.

In other words, one aspect of the present invention provides a titanium-copper alloy having high strength and excellent conductivity as a copper alloy comprising:

three to four percent by mass of Ti,

residual Cu, and

inevitable impurities,

wherein the area percentage (S(%)) of a Cu-Ti intermetallic compound phase observed in a section perpendicular to the rolling direction is represented by the following formula:

$$S(\%) \geq 8.1 \times [Ti] - 17.7$$

where [Ti] represents the Ti content in percent by mass.

According to the present invention, a conductivity is 16% IACS or more, 0.2% proof stress is 800 MPa or more.

Another aspect of the present invention provides a method of producing the titanium-copper alloy described above comprising the steps of:

hot-rolling, cold-rolling, solution-treating, cold-rolling, and aging an ingot,

wherein a cold working degree prior to the aging is 15% or more, the aging temperature is from 350°C to 450°C, the aging time is from 5 to 20 hours, and the average cooling rate from the aging temperature after the aging to 300°C is 50°C/h or less.

According to the present invention, a copper alloy is provided having excellent strength and conductivity that can be used in small, thin electronic devices.

The numerical limitations of the present invention will now be described below:

(1) Conductivity and 0.2% proof stress

When the titanium-copper alloy having increased conductivity is used as a connector, contact electrical resistance and the amount of heat produced due to the flow of a current are decreased. If a conductivity of the titanium-copper alloy is 16% IACS or more, the contact electrical resistance and the heating value reach the same level as those of the high beryllium-copper alloy.

Accordingly, the conductivity is set to 16% IACS or more. More preferably, the conductivity is 20% IACS or more.

When the titanium-copper alloy having a reduced 0.2% proof stress is used as a connector, the contact pressure is decreased but contact electrical resistance is increased. If the 0.2% proof stress is less than 800 MPa, an electrical contact resistance having the same value as that of the high beryllium-copper alloy cannot be provided, even if the conductivity is adjusted to 16% IACS or more. Accordingly, the 0.2% proof stress is set to 800 MPa or more.

(2) Titanium concentration

When the titanium-copper alloy was subjected to the aging treatment, a spinodal decomposition was produced, changing the titanium concentration in the base material, and resulting in a very high strength. If the titanium content is less than 2.5 percent by mass, a proof stress of 800 MPa or more cannot be provided following aging treatment to provide a conductivity of 16% IACS or more, as described below. On the other hand, if the titanium content exceeds 4.5 percent by mass, a productivity is significantly decreased due to the appearance of cracks upon rolling. Moreover, it is difficult to provide a conductivity of 16% IACS or more, even if the aging conditions are adjusted. Accordingly, the titanium content is within the range of 2.5 to 4.5 percent by mass.

(3) Area percentage of the Cu-Ti intermetallic compound phase

It is known that the conductivity is decreased when a solute element is dissolved in Cu, and known to be Ti is an element that significantly decreases conductivity (see G. Ghosh, J. Miyake, M. E. Fine, JOM, vol. 49, No. 3, March, 1997, pp. 56-60). In order to increase the conductivity of the titanium-copper alloy, it is important to deposit a sufficient amount of Ti and to reduce amount of dissolved Ti as low as possible. In other words, when the amount of the Cu-Ti intermetallic compound phase is increased, the conductivity is increased. When a fine Cu-Ti intermetallic compound phase is deposited, the material can have high strength.

The present inventors have discovered that a conductivity exceeding 16% IACS can be provided when the following equation is satisfied:

$$S(\%) \geq 8.1 \times [Ti] - 17.7$$

where S(%) represents the area percentage of a Cu-Ti intermetallic compound phase observed in a section perpendicular to the rolling direction, and [Ti] represents the Ti content in percent by mass.

In addition, the present inventors have discovered that a conductivity exceeding 20% IACS can be provided when the following equation is satisfied:

$S(\%) \geq 8.1 \times [Ti] - 12.7$

where S(%) represents the area percentage of a Cu-Ti intermetallic compound phase observed in a section perpendicular to the rolling direction, and [Ti] represents the Ti content in percent by mass.

(4) Aging conditions

In order to adjust the amount of the Cu-Ti intermetallic compound phase deposited that satisfies the equation $S(\%) \geq 8.1 \times [Ti] - 17.7$, it is important to select adequate aging conditions in the method of producing the titanium-copper alloy comprising the steps of hot-rolling, cold-rolling, solution-treating, cold-rolling, and aging the ingot. In order to increase the S (%), the aging conditions are adjusted as follows:

I. Increase the aging temperature up to the upper limit of 450°C.

II. Prolong the aging time.

III. Slow the cooling rate upon aging. In this case, a cooling rate at an aging temperature of 300°C or more is important.

IV. Increase the cold working degree prior to the aging. By cold-rolling, distortion is produced. This distortion increases the deposition rate of the Cu-Ti intermetallic compound phase.

On the other hand, when the Cu-Ti intermetallic

compound phase is significantly increased during the aging, the 0.2% proof stress is decreased. When the above-mentioned measures I and II are performed, the Cu-Ti intermetallic compound phase is increased. Accordingly, the aging temperature and the aging time should be adjusted within a range such that the Cu-Ti intermetallic compound phase is not so increased, and the 0.2% proof stress is not decreased to less than 800 MPa. However, when the above-mentioned measure III is performed, the Cu-Ti intermetallic compound phase is not increased. In this case, only the S (%) requires adjusting.

The above-mentioned measures III and IV have been newly found in the present invention. A combination of I, II, III and IV can provide a titanium-copper alloy having a conductivity of 16% IACS or more and a 0.2% proof stress of 800 MPa. Specific conditions are as follows:

i. the cold working degree prior to aging is 15% or more.

ii. the aging temperature is from 350°C to 450°C.

iii. the aging time is from 5 to 20 hours.

iv. an average cooling rate from the aging temperature after the aging to 300°C is 50°C/h or less.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Using electrolytic copper as a raw material, each ingot having a width of 60 mm, a thickness of 30 mm and a

composition shown in Table 1 was molded in a high frequency vacuum melting furnace, hot-rolled at 850°C to a thickness of 8 mm, cold-rolled, and solution-treated. In the solution-treating, the ingot was heated at 800°C for 1 min, and then cooled at a rate of approximately 1000°C/sec. Thereafter, the ingot was cold-rolled and aged. By changing the rolling working degree prior to the aging as well as the aging conditions, the amount of the Cu-Ti intermetallic compound phase was changed. The aging temperature, the aging time, and the cooling rate were changed. After the sample was heated at a predetermined temperature for a predetermined time, the cooling rate of the sample was measured. A thermocouple was attached to the sample in order to measure the temperature. An average cooling rate from the aging temperature to 300°C was determined.

The 0.2% proof stress, conductivity and area percentage of the Cu-Ti intermetallic compound phase were then determined. The 0.2% proof stress was measured using a tensile tester in accordance with JIS Z 2241. The conductivity was measured in accordance with JIS H 0505.

The area percentage of the Cu-Ti intermetallic compound phase was measured as follows: the surface of the material to be tested was a section perpendicular to the rolling direction. The cut sample was abraded using #150 waterproof abrasive paper, mirror-abraded with a finishing abrasive

containing colloidal silica having a particle size of 40 nm, and then carbon vapor-deposited. A reflected electron image within a 500 μm^2 visual field was photographed at 20,000 X magnification using FE-SEM. The area percentage of the Cu-Ti intermetallic compound phase was measured from the photo using an imaging device. The Cu-Ti intermetallic compound phase had an area of 5 x 10^{-4} μm^2 or more.

TABLE 1

	No.	Ti content, [Ti] (mass%)	Working degree (%)	Aging temperature (°C)	Aging time (h)	Cooling rate (°C/h)	Area percentage of Cu-Ti phase, S(%)	Conductivity (%IACS)	0.2% proof stress (MPa)	S'=8.1[Ti]-17.7 (%)	ΔS=S-S' (%)
Example	1	4.25	60	380	13	33	22.1	20.1	954	16.7	5.4
	2	4.16	35	370	13	28	19.5	17.1	971	16.0	3.5
	3	4.28	50	360	10	41	17.5	16.2	998	17.0	0.5
	4	3.21	60	380	13	23	14.0	20.5	887	8.3	5.7
	5	3.18	30	420	15	49	11.3	17.4	913	8.1	3.2
	6	3.24	40	400	8	16	9.2	16.4	921	8.5	0.7
	7	2.62	20	450	13	21	10.9	21.2	816	3.5	7.4
	8	2.54	35	430	10	35	5.5	17.7	821	2.9	2.6
	9	2.57	45	420	10	48	4.5	16.7	824	3.1	1.4
Comparative Example	10	4.63	Cracked upon cold-rolling				-	-	-	-	-
	11	2.25	45	420	13	54	2.3	16.5	781	0.5	1.8
	12	4.22	5	360	10	37	10.0	11.2	912	16.5	-6.5
	13	3.14	60	310	13	25	0.6	6.8	742	7.7	-7.1
	14	2.50	20	450	2	19	1.5	14.7	803	2.6	-1.1
	15	3.23	30	420	15	1263	3.1	12.5	883	8.5	-5.4
	16	3.20	30	420	15	566	5.0	13	875	8.2	-3.2
	17	3.25	30	420	15	87	7.6	15.5	861	8.6	-1.0
	18	4.31	20	500	13	48	23.5	21.4	744	17.2	6.3
	19	2.66	35	480	10	34	12.2	23.0	711	3.8	7.9
	20	3.33	40	400	30	56	13.6	18.5	730	9.3	4.3

As shown in Table 1, all Example Nos. 1 to 9 according to the present invention satisfied the equation $S(\%) \geq 8.1 \times [Ti] - 17.7$, had a conductivity of 16% IACS or more and a 0.2% proof stress of 800 MPa or more. In particular, Example Nos. 1, 4 and 7 satisfied the equation $S(\%) \geq 8.1 \times [Ti] - 12.7$, ($\Delta S=S-S' \geqq 5$) and had a conductivity of more than 20% IACS. In the Examples, the cooling rate after aging was 50°C/h or less.

On the other hand, Comparative Example 10, having a Ti content of more than 4.5% by mass, cracked during the cold-rolling, and the test could not be continued. Comparative Example 11, having a Ti content of less than 2.5% by mass, had a 0.2% proof stress of less than 800 MPa when it was aged under conditions where a conductivity of 16% IACS or more was provided.

Comparative Example 12 had a low cold working degree prior to the aging, Comparative Example 13 had a low aging temperature, Comparative Example 14 had a short aging time, and Comparative Examples 15 to 17 had a high cooling rate upon aging, and none satisfied the equation $S(\%) \geq 8.1 \times [Ti] - 17.7$, and did not have a conductivity of 16% IACS or more. Although Comparative Examples 18 to 20 satisfied the equation $S(\%) \geq 8.1 \times [Ti] - 17.7$, and had a conductivity of 16% IACS or more, Comparative Examples 18 and 19 had too high an aging temperature, and Comparative Example 20 had

too long an aging time, resulting in a significantly increased Cu-Ti intermetallic compound phase. Each 0.2% proof stress of Comparative Examples 18 to 20 was less than 800 MPa.